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Topology optimized nanoparticles for near-infrared enhanced photon upconversion

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Abstract:
This work is a part of the SunTune project which addresses efficiency improvements of solar modules by manipulating the spectrum of sunlight to better match the range of efficient current generation in silicon solar cells. Photons with energies below the band gap energy of silicon (*<1.1eV*) are (up)converted into photons with higher energies through absorption in rare earth ions (Er^{3+}) followed by radiative decay. This process converts otherwise non-absorbed long wavelength photos to shorter wavelength photons able to bridge the band gap energy and contribute to the energy generation of the solar modules.

The upconversion process is naturally inefficient, and without any enhancement of the incident light, the process is negligible. The probability for upconversion can be increased by focusing the incident light into areas doped with Er^{3+}ions, using optimized nanoparticles placed into or near these areas. Studies have shown that the intensity of the upconverted light is proportional to the intensity of the incident light raised to some power, n, [1]. Experimentally n is found to be 1.5 and the light intensity is proportional to the square of the electric field norm, $|E|^2$.

We aim to enhance the incident light using topology optimized nanoparticles. Here, the distribution of nanoparticle material is optimized to enhance $|E|^3$ in a thin Er^{3+} doped TiO_2 film. Topology optimization has previously proven successful for optimizing wave propagation in acoustics [2] and electromagnetics [3,4]. The governing physics is modeled classically using Maxwell equations in the frequency domain. The model is excited by an incoming plane wave with a wavelength, within the near-infrared absorption band of Er^{3+} (1480nm - 1560nm).

Keywords: Topology optimization, nanooptics, photolvoltaics, plasmonics, light enhancment

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